Sound Transmission Through Perforated Screens

By Michael Rettinger

This paper describes the high-frequency attenuation of sound waves passing through perforated motion-picture screens of the matte white variety. For the same percent of open area, a screen with smaller-diameter circular holes has fewer treble losses than one with larger-diameter holes. There is a limit to this effect, which occurs when the diameter of the hole is equal to or smaller than the thickness of the screen, at which point viscous losses occur in the cylindrical holes. The paper is not all-inclusive but should lead to further investigation on the part of screen and loudspeaker manufacturers.

Perforated plastic materials of less than one-mm thickness are often employed as front-projection screens of the matte white variety.

No ANSI standards describe the perforations in motion-picture screens, although the subject was prepared as a standard in 1945 (252.44), and approved as an American National Standard in 1951 (PH 22.82). However, it was withdrawn in 1963.

British Standard BS 5382:1967 states that the 6000-Hz sound pressure level shall not be attenuated by more than 3 dB, and the 8000 Hz level by no more than 6 dB at the screen compared to the sound pressure level at 500 Hz.

The mathematics of sound transmission through apertures has attracted the attention of acousticians for many years.[1-6] Such analyses generally relate to screens with perpendicular sound incidence, wavelengths greater than the circular-hole diameter, and screen thicknesses not greater than the hole diameter.

The derivations of the equations are lengthy. Some progress has been made with some results reported by F. Bruckmayer and C. L. Morvey,[2,3] who investigated these types of screens while studying facings for sound-absorbent materials. They concluded that when

a = sound energy absorptivity for normal sound incidence

$$= \frac{1}{1+\left(\frac{\pi f C^2}{Dc}\right)^2} = \frac{1}{1+\left(\frac{.0913FD}{PC}\right)^2}$$

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Hence TL = sound transmission loss for normal incidence

$$= -10 \log a$$

$$= 10 \log \times \left[1+\left(\frac{.0913FD}{PC}\right)^2\right]$$

where C = center-to-center distance between holes, in centimeters

D = hole diameter, in centimeters

f = frequency, Hz

F = frequency in kHz

PC = percent of open area of screen, that is, the ratio of the perforations to the total area of the screen

c = velocity of sound in air, 34,400 cm/sec

The perforations in a screen may be laid out so that the hole centers are equidistant, C, along two sets of parallel straight lines which are at right angles to each other, a pattern known as "straight hole arrangement," or they may be staggered so that the holes are equidistant, C, along one straight line and equidistant, C, along another straight line at a 60° angle to the first straight line, a pattern known as "staggered hole arrangement" shown in the lower part of Fig. 2. With the latter arrangement more holes are possible per unit area for a given C, and can be calculated by:

n = number of holes per unit length both horizontally and vertically in "straight hole arrangement," equal to $1/C$

n' = number of holes per unit length vertically in "staggered hole arrangement," while horizontally

$$n = \frac{1}{C \cos 60°} = \frac{1}{.866C}$$

$$= \frac{1.1547}{C}$$

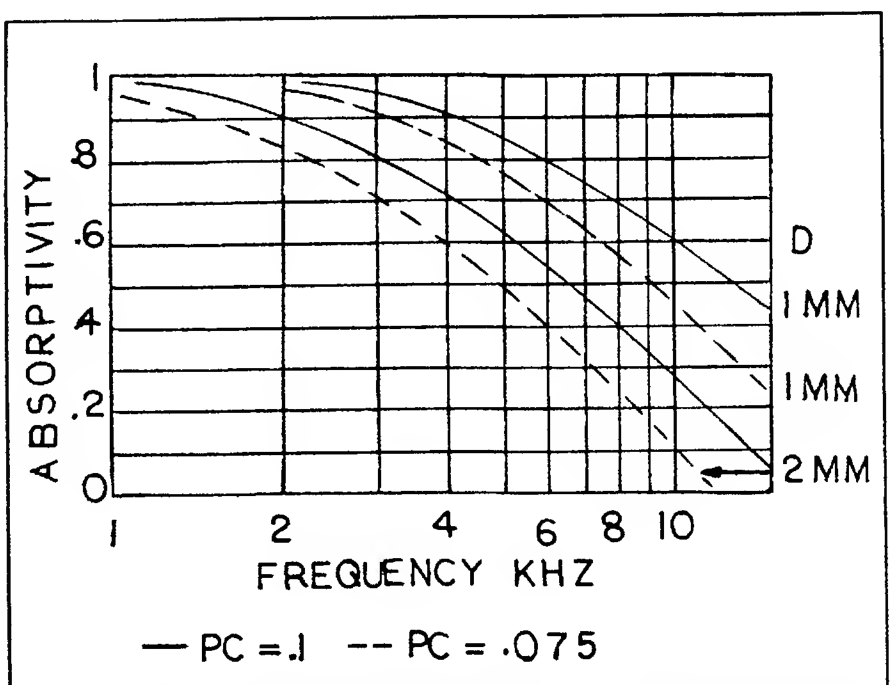

Figure 1. Absorption characteristics of perforated screens. PC is the percent of open area of screen; D is the diameter of holes.

N = number of holes per unit area for "straight hole pattern"

$$= n^2 = \frac{1}{C^2}$$

N' = number of holes per unit area for the "staggered hole pattern"

$$= nn' = \frac{1.1547}{C^2}$$

A = area of hole, cm^2

$$= \frac{\pi D^2}{4}$$

PC' = percent of open area for "staggered hole pattern"

$$= N'A = \frac{.9069D^2}{C^2}$$

PC = percent of open area for "straight hole pattern"

$$= NA = \frac{.785D^2}{C^2}$$

Thus, for the same unit area, the "staggered hole pattern" can provide .9069/.785 = 1.155, or 15.5% more holes than the "straight hole pattern."

Interestingly, more than 50 years ago, H. F. Hopkins of Bell Telephone Laboratories wrote an article in the *Journal of the SMPE*[7] about perforated screens, without, however, any mathematical explanations on the subject. As in his discussion, the effects of diaphragmatic action on the part of the screen and internal viscous losses are also not considered in the following.

Figure 1 shows the absorption characteristic of two types of screens: one with 10% open area and one with 7.5% open area, each type perforated with 1- and 2-mm diameter holes.

Figure 2 represents the sound transmission loss characteristics of these two types of screens with different diameter holes.

It can be seen that, *for the same percent of open area*, the screen with the smaller-diameter holes exhibits a larger absorption at the higher frequencies than the screen with the larger-diameter holes. By the same token, the screen with the smaller-diameter holes has less sound transmission loss in the treble than the screen with the larger-diameter holes.

The question may be asked, can a perforated screen with an open area as small as 10% and 1-mm-diameter holes absorb practically 90% of the incident sound energy below 4000 Hz?

The reason lies in the fact that the

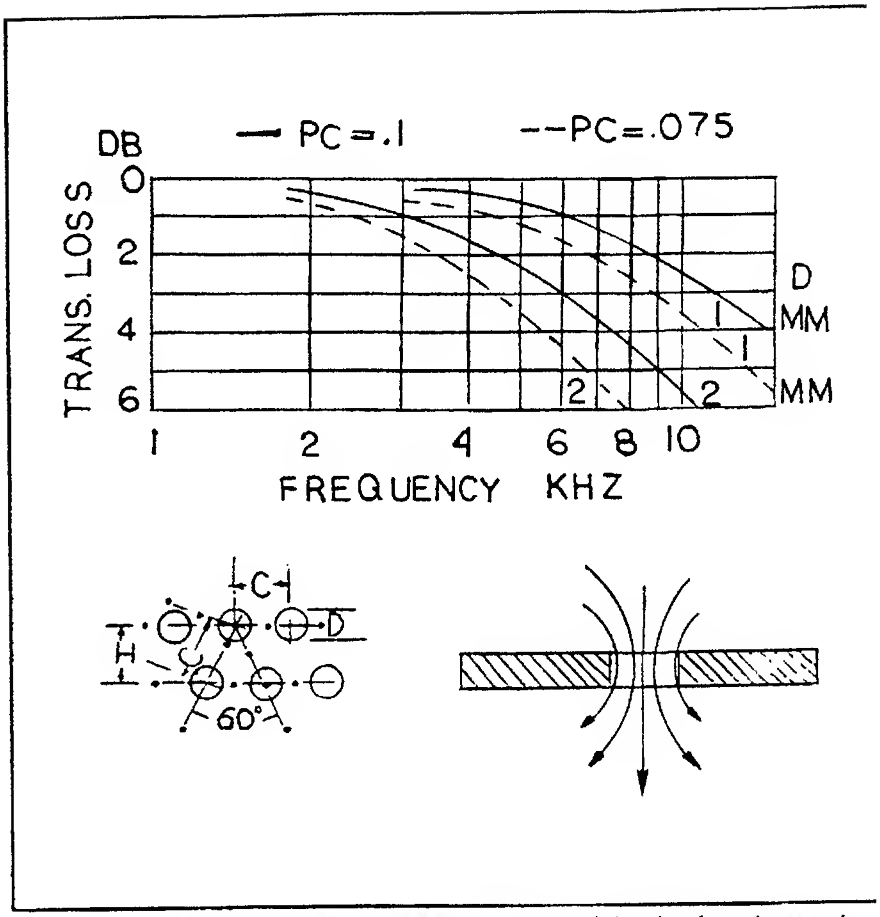

Figure 2. Upper diagram shows sound transmission loss characteristics of perforated screens. Low left diagram illustrates the "staggered hole pattern" of perforations. Lower right diagram illustrat air-particle motion through the hole.

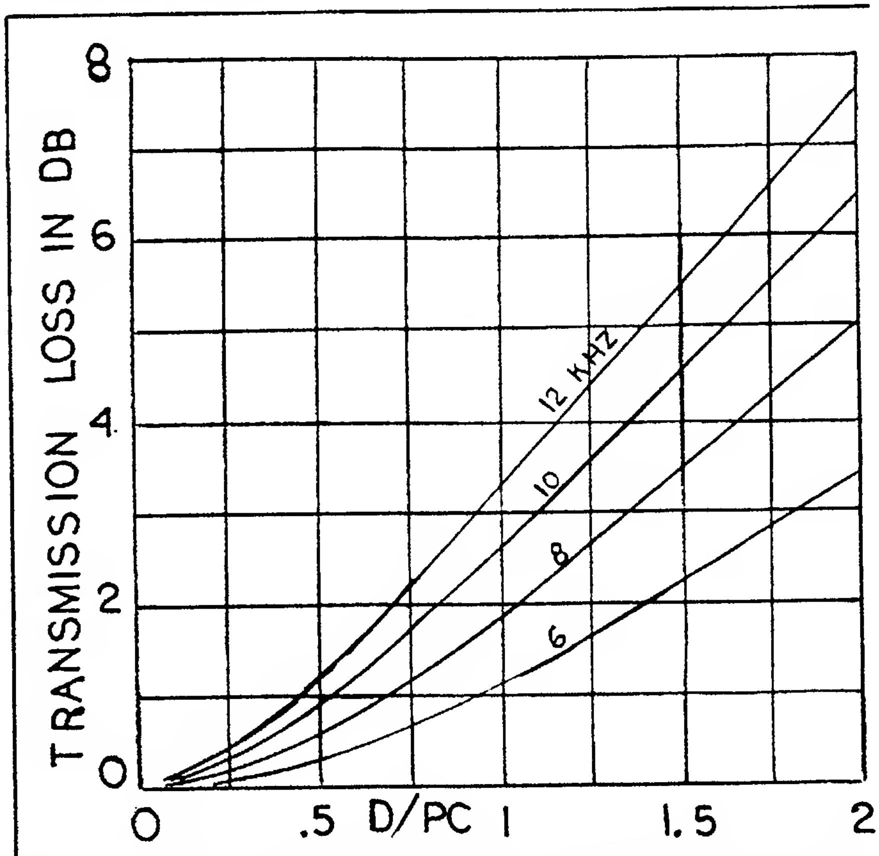

Figure 3. Variation of sound transmission loss with a ratio of hole diameter to percent of open are for various frequencies.

holes represent a low-pressure area, while the adjacent unperforated hard parts of the screen (where the air particle velocity is at a minimum) experience a higher pressure than exists for the signal in free space. At the same time, on the other side of the screen, the unperforated part is a low-pressure area because no sound is incident upon it, and the holes on that side are high-pressure surfaces. Therefore, the incident sound waves are sucked into the holes on the sound-incident side of the screen, while behind the screen, the waves are fanned out as illustrated on the lower diagram of Fig. 2.

Below 500 Hz the above equations are approximate because at the bass notes the screen will move like a diaphragm and absorb energy by mechanical vibration.

The above equations and graphs indicate that motion-picture screens should, for the same open area, employ small-diameter holes to minimize high-frequency sound transmission losses.

Similar considerations hold for microphone windscreens and TV projection screens, such as the 20-ft picture width employed in the GE PJ700 TV projector, particularly when stereo sound-reproduction is required.

There may be a question whether, for the same open area, a screen with small-diameter holes will absorb more light than a screen with larger-diameter holes, or whether the same amount of light is absorbed by both screens.

Figure 3 shows the variation in the sound-transmission loss (TL) according to the ratio between the hole diameter (D) in centimeters, and the percent of open area for different frequencies. As an example, when the hole diameter is 1 mm and the PC is 10%, then at 10 kHz the TL is 2.6 dB.

Figure 4 shows the variation in the number of circular holes per square cm, N, with a hole diameter (D) in cm for various percentages of open areas in perforated screens. The pertinent equations are

$$N = \frac{1.273\,PC}{D^2}$$

$$= \frac{1.155}{C^2}$$

"staggered hole pattern"

$$= \frac{1}{C^2}$$

"straight hole pattern"

Since the matte white screens are generally not thicker than .8 mm, the hole diameter may not be smaller than 1 mm when the percent of open area is 10% and the frequency is 10 kHz. For design purposes, therefore, D/PC should be no smaller than .5 and not greater than 1.5, so that the sound transmission loss is no greater than 4 dB at 10 kHz.

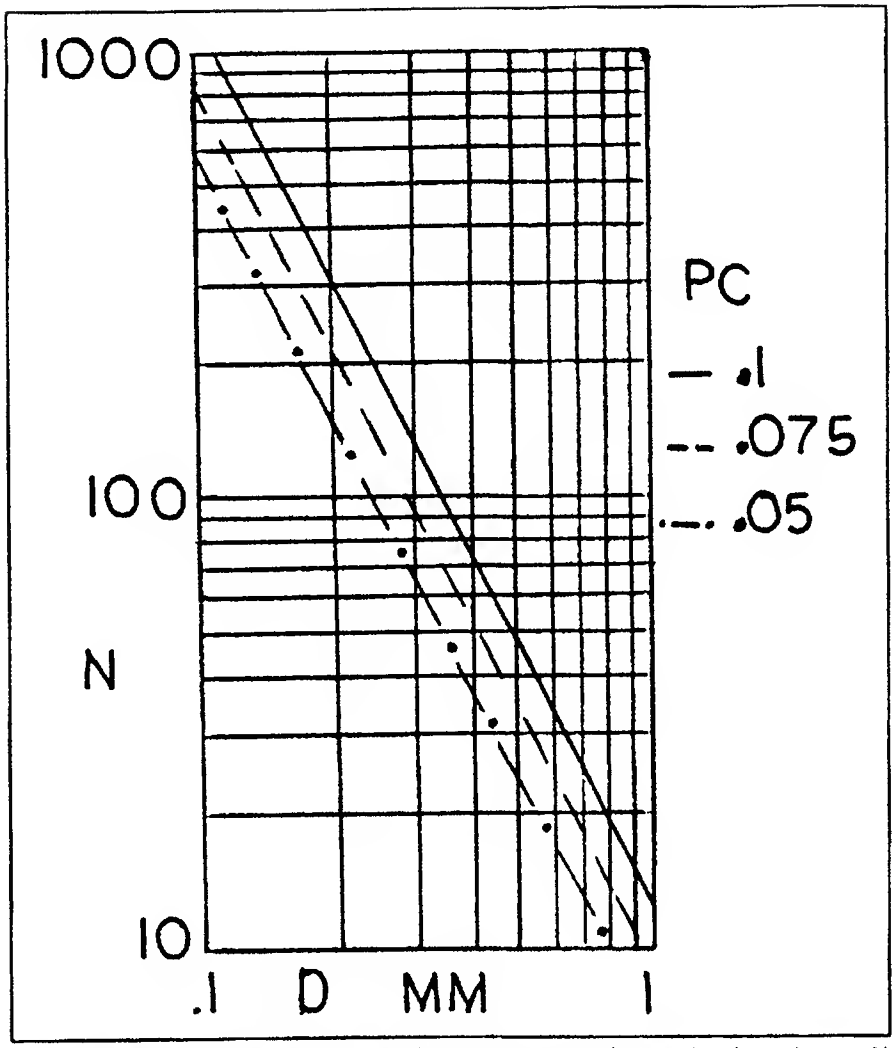

Figure 4. Variation in the number of circular holes per square centimeter of perforated screen, N, with hole diameter for various percentages open areas in the screen.

In association with the high-frequency losses of perforated screens, phase distortion occurs because the air-particle velocity in the holes is greater than that of sound waves in free air. This type of distortion can easily be demonstrated by listening to a musical program rich in treble, first without the screen in place, and then when the loudspeaker is faced with it. The effect is not so much one of changed frequency response on the part of the signal but one of clarity, presence, and distinction.

With the velocity of sound in vinyl and cellulose acetate sheets at least three times that in air, the angle of refraction for small angles of incidence is three times the angle of incidence, according to the law of refraction, which states

$$-\frac{\sin i}{\sin r} = \frac{V_1}{V_2}$$

where i = angle of sound incidence
r = angle of refraction
V_1 = speed of sound in medium 1
V_2 = speed of sound in medium 2.

Thus, when a sound wave travels obliquely from the air to and through the vinyl, the ratio of the sine of the angle of incidence to the sine of the angle of refraction is the same as the ratio of the wave velocities in the two media. This is shown graphically in Fig. 5, where the angle of sound incidence on the vinyl was assumed to be five degrees, and the angle of refraction to be three times as large (15 degrees). Similarly, as the sound wave leaves the vinyl, the angle of refraction again becomes five degrees. The sound energy spreads along the plastic sheet,

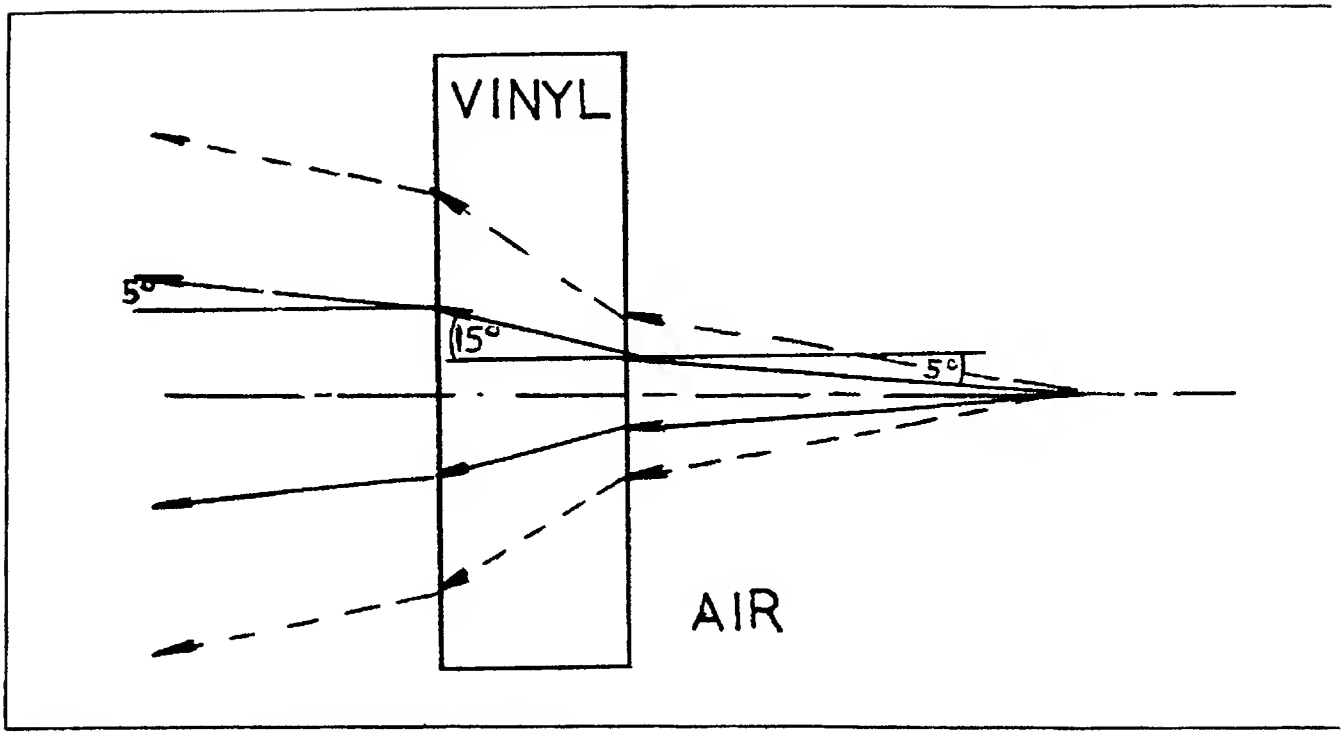

Figure 5. Refraction of sound wave passing through a vinyl screen.

so that the sound-pressure reduction is closer to the normal of the membrane, as was found by Ted Uzzle and Rex Sinclair.[8] A similar refraction effect is due to the higher velocity of the sound waves leaving the screen, which also results in spreading of the energy along the membrane, as shown in Fig. 2.

Because of the lateral scattering of the sound energy after transmission through a perforated screen, it is desirable to determine its sound-power transmission-loss characteristic rather than the sound-pressure transmission-loss characteristic at a fixed angle of transmission. This may be done in the open or in an anechoic chamber by measuring, at a given frequency, the SPL over zones of a hemisphere and then calculating the logarithmic sum, so that the sound-power level WL referred to as 10^{-12} watts equals

$$WL = \sum\left(SPL_i = 10 \log \frac{S_i}{S_o}\right)$$

where S_i = area of hemispherical zone in square meters

S_o = reference area, 1 m^2

SPL_i = sound pressure level pertaining to zone i, decibels.

The sound power level of the transmitted signal may also be obtained in a reverberation chamber by the equation

$$WL = SPL + 10 \log A - 6$$

where A = sound absorption in chamber in square meters.

To obtain a good measure of the SPL, it is necessary, given a fixed frequency, to average the SPLs in the room because of possible standing waves, or to employ narrow frequency bands of random noise.

The sound-power transmission loss would then be the difference in the measured sound-power levels obtained with and without the screen placed between the sound source and the microphone, at all test frequencies.

No articles have been found showing whether motion-picture screen manufacturers have done research on the optimum design of matte white perforated screens. Insufficient economic motives may have discouraged such design activity, particularly now, during a time of economic recession. Information of this kind will probably have to be sought by private investigators, possibly by physics departments in our technical colleges, and manufacturers of electroacoustic devices, such as loudspeaker manufacturers, whose products have a peripheral bearing on the quality of perforated screens.

Appendix

Several theoretical approaches to the problems of sound absorption and sound transmission through thin, perforated panels have been employed by researchers. In the piston theory, for example, a thin, massless piston is made to move in the holes of a thin perforated panel. This results in high-frequency diffraction effects at the edges of the holes, if there is uniform sound pressure across the opening. The experimental verification of any of these approaches is difficult because minuscule microphones are required to move across the holes of a thin panel to explore the pressure distribution across the holes. K. A. Mulholland and D. H. Parbrook[5] found, by employing large holes and a relatively small microphone, that the pressure was far from uniform across the hole. The pressure decreased more and more towards the center of the hole for the frequencies referred to in this article.

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